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The agroecological transition
of agricultural systems in the Global South

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Chapter 4

Anti-insect nets to facilitate the agroecological transition in Africa

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African market gardening at an impasse

Market gardening has experienced considerable growth in sub-Saharan Africa over the last 50 years, especially on the periphery of major urban centres. While African leafy vegetables (African eggplant, amaranth, celosia, etc.) are mainly grown in rural areas, so-called 'exotic' vegetables (tomato, lettuce, carrot, cabbage, etc.) are primarily grown intensively in peri-urban market gardens or in large open fields, especially in the case of tomatoes grown at an industrial scale (Huat, 2006).

Intensive and unsuitable use of phytosanitary products

Various surveys of the phytosanitary practices of small market gardeners in sub-Saharan Africa conducted over the last 20 years have shown that, in both rural and urban areas, there is widespread reliance on intensive chemical control in order to cope with the many pests and diseases of crops (Ahouangninou *et al.*, 2011; de Bon *et al.*, 2014; Azandémè-Hounmalon *et al.*, 2015; Abtew *et al.*, 2016). These same authors also note the recourse to phytosanitary practices that put humans and their environment at risk: excessive doses of formulations and frequencies of application, frequent diversions of use (for example, phytosanitary products meant for the cotton sector), unspecific broad-spectrum pesticides (often associations of several active ingredients), manual methods of application that are not very effective and dangerous for the users (for example, use of watering cans for applying the products), spraying without protection, unsuitable irrigation practices, and/or phytosanitary applications under uncontrolled conditions (proximity to water points, during unsuitable weather, etc.) leading to risks of transfer of chemical molecules to different compartments of the environment (surface water, groundwater, atmosphere) (Diop *et al.*, 2016). A recent survey conducted in Kenya in the tomato production region reveals that, according to over 85% of 'small' producers, this field crop cannot be cultivated without weekly or bi-monthly chemical treatments given the current pressure from pests and diseases (Nguetti *et al.*, 2018).

Resistance, invasions

As a result of four to five decades of continuous use of phytosanitary products, African market gardeners find themselves at a technological deadlock: phytosanitary products are becoming less and less effective because of the selection of resistant pests such as the tomato moth *Helicoverpa armigera* (Martin *et al.*, 2002), the aphid *Aphis gossypii* (Carletto *et al.*, 2010), the whitefly *Bemisia tabaci* (Gnankiné *et al.*, 2013) and the cabbage moth *Plutella xylostella* (Agboyi *et al.*, 2016). The use of pesticides also leads to the decline in the numbers of natural enemies (predators and parasitoids) that regulate populations of local pests but which can also adapt to new pests that arrive without their natural enemies such as the oriental fruit fly *Bactrocera dorsalis* (Vayssière *et al.*, 2011), the red spider mite *Tetranychus evansi* (Azandémè-Hounmalon *et al.*, 2015) and, most recently, the tomato moth *Tuta absoluta* (Chailleux *et al.*, 2017).

The trap of the 'chemical only' solution

Small African producers face a number of constraints that lock them into the trap of an 'chemical onlyl' solution.

The private-sector advisory system encourages chemical control. In sub-Saharan Africa, technical advice to producers is dispensed by the private sector (seed companies, manufacturers and distributors of phytosanitary products). Knowledge of inputs and varieties available to small producers is therefore focused around chemical control (Nguetti *et al.*, 2018). The structural adjustment plans of the 1990s of the World Bank and the IMF led to the dismantling of extension services in the name of market liberalization and disengagement by the State. However, these advisory services are currently undergoing a reconstruction, with NGOs becoming active stakeholders.

Procurement pricing rules encourage the elimination of pests. In sub-Saharan Africa, domestic fresh fruit and vegetable markets emphasize the visual quality of products and their firmness to reduce transport and storage losses. No added value is accorded to the environmental and health quality of products. Thus, to prevent their crops from being inadequately valued, producers resort to chemical control to eliminate pests and diseases that cause pitting and/or blemishes on fruits.

The informal sector is significant in size. In most sub-Saharan African countries, the situation is often compounded by little or no regulation of the sale and use of phytosanitary products and/or of pesticide residues on or in products destined for local markets as opposed to products for export.

There is a lack of training of small producers. Under these conditions, it is difficult to promote alternative methods such as biological control. Market gardeners in sub-Saharan Africa are encouraged to follow the advice of their neighbours or their suppliers, who provide training/advice through the prism of chemical control (Nguetti *et al.*, 2018).

Nevertheless, consumer demand for healthy vegetables is starting to grow, especially in African mega-cities and, to a smaller extent, even in rural areas. In response, some supermarkets have started selling 'bio' or organic vegetables. Small markets offering local fruits and vegetables produced without pesticides have appeared in some neighbourhoods, and some producers in Abidjan, Cotonou and Nairobi have started delivering baskets of organic vegetables[1]. In rural areas, initiatives are also emerging among producer associations aware of the toxicity of chemical pesticides and the need for healthy fruit and vegetables for the sake of good health and the environment. In sub-Saharan Africa, NGOs such as Songhai, Enda Pronat and Agrisud have also been involved for several years in training producers in agroecological farming techniques.

Bottom up agroecological practices

Protecting crops through physical means

For the past 15 years, CIRAD has been experimenting with and proposing market gardening systems based on the principles of physical protection of leafy vegetable and fruit crops, in different climatic zones of West and East Africa (Nordey *et al.*, 2017). This work is being carried out in close collaboration with national research centres (INRAB, KALRO, ISRA)[2], international ones (ICIPE[3], World Vegetable Center) and universities (Abomey-Calavi, Benin; Egerton, Njoro; Péléforo-Gbon-Coulibaly, Korhogo; Felix-Houphouet-Boigny, Abidjan; Michigan State, Lansing; California, Davis) with financial support from CIRAD and USAID HIL[4]. Experiments on techniques in research stations were followed by demonstrations on producers' farms to assess together the performance of these new practices. The most promising innovation is the use of nets that provide a climate-friendly environment for cultivation while protecting crops from larger pests. Anti-insect nets were designed and adapted to agroclimatic conditions in three African countries (Benin, Senegal and Kenya). Cost/benefit analyses were then conducted to estimate the financial viability of this technology for small producers (Vidogbéna *et al.*, 2015a).

The effectiveness of nets in controlling pests

Our results have shown that the use of anti-insect nets leads to a considerable reduction in pest attacks, especially from those responsible for direct damage to the production of fruits (tomato, bean) or leaves (cabbage), such as birds, snails, caterpillars, flies and locusts (Martin *et al.*, 2006, 2015; Saidi *et al.*, 2013; Gogo *et al.*, 2014; Simon *et al.*, 2014). Depending on their mesh size, nets allow the crops to get sufficient aeration – ventilation needed to avoid a confinement of crops that would lead to fungal diseases –, even under tropical conditions. On the other hand, these nets do not completely protect crops against phloem-feeding pests such as aphids, whiteflies, thrips and phytophagous mites. They can, however, significantly reduce infestations of some whiteflies (*Trialeurodes* sp.) on tomatoes compared to crops not protected by nets (Figure 4.1). This technique has the advantage of being financially affordable and of being able to provide effective protection against certain emerging pests. This is especially the case for the tomato moth *Tuta absoluta* where the use of a physical

1. For example, see https://www.youtube.com/watch?v=Qy8WZfT0DqE (retrieved 17 February 2019).
2. Respectively National Institute of Agricultural Research of Benin, Kenya Agricultural and Livestock Research Organization, and Senegalese Institute of Agricultural Research.
3. International Centre of Insect Physiology and Ecology.
4. United States Agency for International Development – Horticulture Innovation Lab.

barrier can delay and reduce damage (Deletre *et al.*, forthcoming). To complete the protection against small pests, it is necessary, on the one hand, to optimize the natural defences of the plants cultivated under nets by ensuring the adaptation of varieties, soil quality (nutritive and microbiome resources), and water supply (micro-irrigation) and, on the other, to put in place compatible and reasoned methods of pest control.

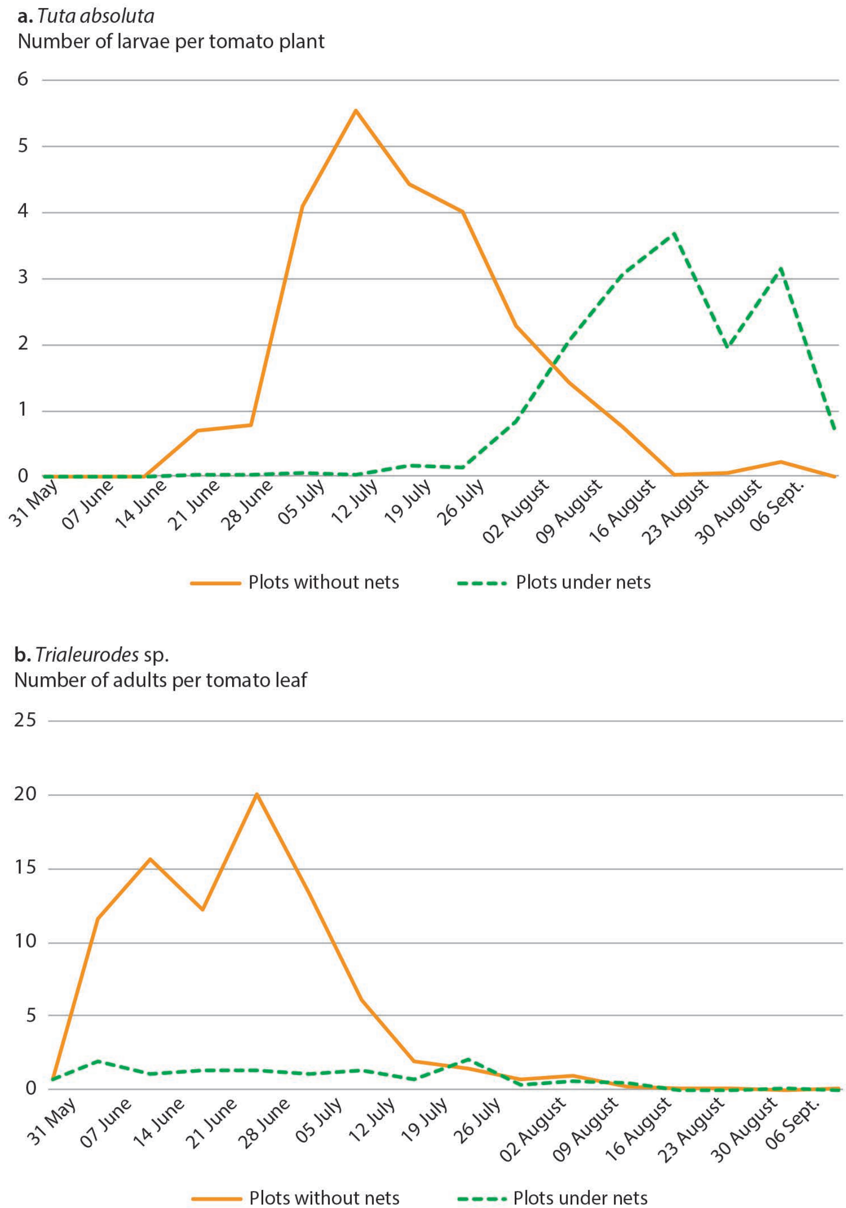

Figure 4.1. Mean number of *Tuta absoluta* (a) and whiteflies *Trialeurodes* sp. (b) per untreated tomato leaf, under nets (dashed line) and outside (solid line), in an experiment conducted in Kenya in 2017 at the Kalro research institute, Mwea.

The limitations of physical control

Physical control is generally but wrongly believed to be the only solution for controlling all pests of a crop. In reality, many insects, usually phloem-feeding ones such as whiteflies, thrips, aphids and mites, and even lepidopterans and flies, end up getting through physical barriers, regardless of the type of barrier used.

In tropical climates, nets with larger mesh sizes are required to increase natural ventilation and reduce temperatures and relative humidity under them (Nordey *et al.*, 2017). This increase in mesh size decreases the level of physical protection against phloem-feeding pests. Some species, but not all, may even proliferate there as they find safety from their natural predators (birds, ladybugs, lacewings, hoverflies) or even their parasitoids, although we have shown that an increase in mesh size could also facilitate the passage of some of these latter species (Martin *et al.*, 2015).

In Benin, for example, cabbages produced under nets are protected from caterpillar attack, but they can become heavily infested with aphids, in a similar way to tomatoes cultivated under nets, which become infested with whiteflies of the *Bemisia tabaci* species. On the other hand, in Kenya, *Trialeurodes* sp. whitefly infestations remain low under nets while they are widespread on tomato or bean crops in open fields (Figure 4.1). Since physical control is not incompatible with chemical control, producers can continue to use the latter. But since they do not want their crops damaged by insects, especially their high value-added crops, they often resort to chemical control with the usual excesses, not knowing all the species of insect pests (and the damage they cause), even less the useful species.

Other agronomic benefits of physical control

This technique is easy to understand and use. It is also relatively well-suited to tropical climates because it is possible to adjust crop shading and ventilation by choosing appropriate colour or mesh size of the net (Nordey *et al.*, 2017). Nets are also useful for protecting crops against extreme weather events such as torrential rains, squalls or droughts. Finally, the use of nets reduces evapotranspiration, and consequently reduces the plant's water needs, in addition to improving the quality of fruits, especially for the tomato, both for its marketing (firmness) and in its organoleptic qualities (better sugar/acidity balance) (Saidi *et al.*, 2013).

Technical support and favourable public policies for the dissemination of this innovation

For what economic profitability?

The economic performance of agroecological innovations can be analysed using an evidence-based policy approach, which originated from the medical sciences (Laurent *et al.*, 2009, 2012). In our case, this amounts to measuring the effectiveness of the use of anti-insect nets, then identifying the prospects for dissemination to a wider population of producers, and finally, assessing the practice's environmental impacts. The profitability analysis is therefore necessary as part of a proof-of-concept approach as well as of an approach for informing the formulation of sectoral economic policies.

It is therefore a matter of inspiring or orienting public or private agricultural policies on the basis of analyses of the economic performance of the innovations being tested. The analysis of the innovations' economic profitability at the farmer level is one of these tools, an analysis which is not solely an exercise in accounting because it is also the concrete, informed and measured representation of the economic system in which the farmer operates. Programmes to demonstrate anti-insect nets to small producers were conducted in Benin (2012-2014) and Kenya (2017-2018). In the first case, it was a matter of transferring the technology of low net-covered tunnels (Photo 4.1) to vegetable growers in southern Benin to protect cabbage crops both in the nursery and in the cultivation areas.[5] In Kenya, the aim was to assess the economic viability of high net-covered tunnels for the production of tomatoes (Photo 4.2), cabbages and green beans in rotation in different geographical zones.[6]

A composite indicator

To analyse these innovations' profitability, we have developed an indicator based on agronomic yields, producer prices and costs. This composite indicator therefore summarizes agronomic performance and market access, and accounts for the supply chains of various inputs used in agricultural production, including the labour market in the form of manpower. Profitability is thus an indicator that reflects not only a natural environment and market relationships, but also their instability and uncertainty. For example, large crop losses due to pest infestations or a surfeit of agricultural supply on agricultural markets can temporarily lower the prices paid to the producer. In both cases, the producer's income is affected.

Profitability of crops cultivated under nets

Profitability in itself is, no doubt, a useful indicator, but an analysis of the profitability compared to that of the alternatives offered to the farmer (or in comparison to his current practices) helps him decide whether he should adopt the proposed innovations. Indeed, economic performance analyses carried out in Benin not only showed that low tunnel anti-insect nets for cabbage production were profitable, but also that this profitability was on average significantly higher when compared to conventional methods, i.e. to those using insecticides (Vidogbéna *et al.*, 2015b). The analyses also showed an increase in yields in real conditions and an improvement in the quality of crops due in particular to the reduction in insecticide applications (a higher proportion of cabbages of larger size and with a better visual appearance for sales). In fact, profitability analyses have shown that nets dampen variations in yields and therefore in incomes. They thus help stabilize cash flows, reduce the volatility of production and variations in quality. This stability over time of financial resources is an important element in reducing the vulnerability of farms and improving their overall resilience. It is therefore also a means of helping the farmer acquire a long-term vision by reducing the risks he can perceive, thus allowing him to make medium-term productive investments at lower levels of risk. Indeed, the producer's decision to invest depends on his expectations, which themselves depend on, among other factors, his perception of risk and uncertainty.

5. https://www.youtube.com/watch?v=FKyJjpC4p2g (retrieved 17 February 2019).
6. https://www.youtube.com/watch?v=Y6Ri6SuWTqk (retrieved 17 February 2019).

Obstacles to and levers for adopting nets

An innovation is adopted after a multi-phase decision-making process: from understanding of how the innovation works to deciding to test and then adopt it (or to adapt it), and, finally, to decide to continue using it over time. Programmes to demonstrate anti-insect nets to small producers in Benin and Kenya were based on *ex ante* approaches, i.e. approaches that anticipated farmers' reactions instead of analysing

Photo 4.1. Cabbage cultivation under low tunnels covered with nets in Benin.
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Photo 4.2. Organic tomato cultivation system under a high tunnel in Kenya.
© Thibaud Martin / CIRAD.

them *ex post*. We found that small producers in Benin were ambivalent about adopting this innovation for protecting their cabbage crops despite a higher predicted profitability than with current practices (Vidogbéna *et al.*, 2016). While a small proportion of producers expressed an immediate interest in adopting this technique (18%), half of them refused to do so and the rest were relatively ambivalent. The farmers who refused to adopt the technique did so because of a perception of abnormally high labour costs. In fact, this result was also predictable. The profitability of an innovation is necessary but not sufficient for its adoption (Rogers, 2003). The required quantitative data must be supported by qualitative and dynamic analyses based on the prospective recipients' perceptions. Aside from evaluating the technology itself, the farmer must also evaluate the context in which this evaluation takes place, i.e., as we have seen, the agronomic context (an area vulnerable to attacks from pests, for example), access to the market and to inputs. Finally, the farmers' perception of the technology itself has to be considered: its comparative advantage, its complexity, its ability to be tried out, and the visibility of the results obtained (Rogers, 2003). Significant variations in this perception should be recorded according to the level of technicality and experience of the farmer in using nets (Vidogbéna *et al.*, 2015b, 2016). Furthermore, the results of *ex ante* analyses of adoption should not obscure the fact that adoption – and more precisely dissemination – is a dynamic process. Indeed, those who refuse to adopt the technique today will perhaps be the adopters or even the pioneers of tomorrow.

Profitability analysis for informing the formulation of targeted policies

A detailed breakdown of the economic performance obtained by a profitability analysis not only reveals favourable production conditions but also helps formulate hypotheses for targeted public or private support policies. In the case of Kenya and green beans, for example, Figure 4.2 breaks down, for eight farmers, the cost/benefit ratio of commercial production in the case of a fully subsidized net and in the case of a non-subsidized net. The red zone represents the breakeven point. This figure shows,

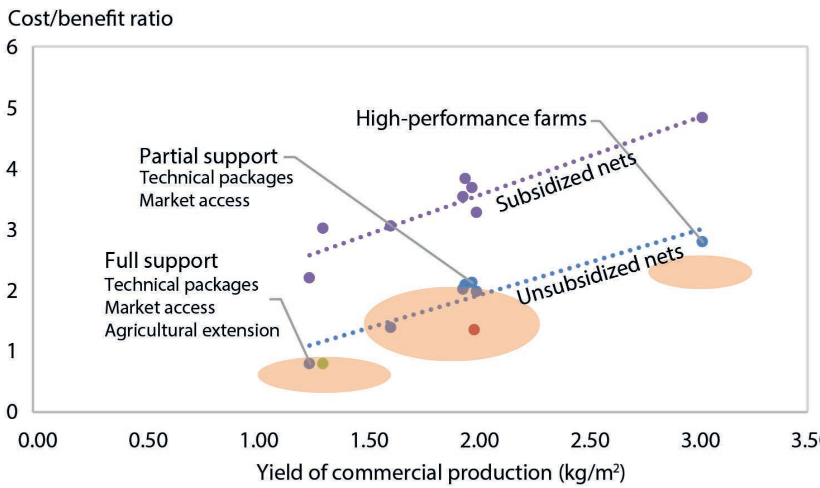

Figure 4.2. Cost/benefit ratio of commercial production in the case of a fully subsidized net and in the case of an unsubsidized net for eight producers in Kenya (Mujuka *et al.*, forthcoming).

on the one hand, contrasting production situations and, on the other, the possible impacts of a subsidy for insect nets and, consequently, the importance of agricultural policies targeted on the basis of farm type.

Contrasting production conditions

As far as situations of commercial production are concerned, it was observed that the farmers monitored in Kenya had a contrasting production experiences. Theoretically, there should be a direct relationship between yield – irrespective of its exact value – and the cost/benefit ratio for commercial production. However, many factors, biotic and abiotic, can affect yields and thus the cost/benefit ratio. In the case of the eight farmers, we observed, for example, a case in which the yield was affected by a plot maintenance contract not respected by an exporter. We also observed low green bean farmgate prices due, in particular, to an election period (departure of foreigners) but also low prices in general. We also observed the importance of good technical mastery and of having high-quality and adapted seed varieties to boost yields. In some cases, agroclimatic zones affect production conditions and trigger chains of causality: an unsuitable environment leads to excessive use of synthetic inputs, which is often inefficient and leads to economic losses.

We have identified three broad groups of farmers: subsistence farmers, farmers in the general mean, and a single pioneer/enterprising farmer. In this breakup, for example, the use of nets is not economically viable for subsistence farms. Indeed, for them, the break-even point is less than 1.

Towards targeted support policies

A typology of the economic performance of innovations under real-world conditions, i.e. made by collecting and grouping all the constraints that affect the farmer's decision-making and the economic performance of the proposed innovations, is also part of evidence-based policy approaches. For formulating support policies, information is necessary that is based on real facts and pertaining to the intended recipients of the innovations, the farmers. We have been able to show some examples of hypotheses of targeted support policies based on observations made in the field. In the case of subsidized anti-insect nets, there would be an automatic improvement in the profitability of all farms. The nets for subsistence farms would break even. As far as targeted agricultural policies are concerned, the dissemination strategy can be either commercial, with the cost of the technology being borne by the farmer, or public, i.e. with the cost covered by a government subsidy in the form of direct aid. Segmented market access strategies could also improve prices or the sharing of added value (short circuits, supermarket contracts, niche markets, etc.). In this connection, pricing policies linked to compliance with various norms and standards would make it possible to offset the costs of implementing quality initiatives. The analysis of economic performance based on profitability analyses of innovations also makes it possible to identify appropriate insurance policies for climatic hazards and economic risk. The issue comes therefore down to studying the economic relationships between the formal sector and the informal sector in which farms operate (de Bon *et al.*, 2014). Finally, adapted agricultural extension policies could improve the appropriation of innovations.

All of these targeted support policies will indirectly impact the profitability analyses of the use of nets. And this impact could furthermore be differentiated according to the agricultural populations: a relatively small population of dynamic farmers running farms well endowed with productive capital; a population of farmers with moderate amounts of capital; and a population of farmers with little productive capital and whose primary goal is food security.

The relationship between support policies and profitability are therefore crucial. To reiterate, targeted agricultural policies for subsistence farms could, for example, consist of subsidizing productive equipment, facilitating the marketing of production through controlled procurement prices, and supporting producers through extension services.

What environmental impacts?

One of the expected benefits of the use of nets is a lower environmental impact of the cropping systems concerned, especially per unit production, due to the high resulting yields, lower use of pesticides and more efficient water use. A life cycle analysis of tomato cultivation in peri-urban market gardens in Benin has revealed that poorly managed agricultural practices (excessive use of pesticides, fertilization and irrigation) associated with generally low yields inevitably lead to very high environmental impacts per unit produced (Perrin *et al.*, 2015; Perrin *et al.*, 2017). With regard to cropping systems with nets, the fundamental question is therefore whether the better yields expected and the lower use of inputs (water and pesticides in particular) will offset the environmental impacts associated with production, transportation and the end of life of the nets themselves. What is the actual contribution of these nets to the overall performance given that the real agronomic performance of these systems is very dependent on the abilities of the producers to manage their cropping systems and on their production constraints? Indeed, we have observed that the use of nets does not necessarily mean lowered use of pesticides. Life cycle analyses carried out on unheated and under-cover market gardening systems have shown the importance of not only the infrastructure and its lifespan, but also of its end-of-life management (Payen *et al.*, 2015; Boulard *et al.*, 2011; Martínez-Blanco *et al.*, 2011; Torrellas *et al.*, 2012).

Extending the life of synthetic materials, recycling them or using organic materials are some of the possible solutions to reduce the environmental impacts of under-cover systems. Management of infrastructure waste is also crucial in the environmental impacts of these systems, especially the rate of recycling of plastics, made more difficult, and thus more expensive, by the possible presence of impurities (soil, pesticides). The energy recovery of plastic waste is an interesting alternative to recycling, with the calorific value of polyethylene, for example, being equivalent to that of diesel. On the whole, the eco-efficiency of under-net cropping systems depends on the levels of use of all kinds of inputs (fertilizers, pesticides, water, soil, energy, nets and other equipment) and on their yields, while remaining very dependent on the abilities of the producers and their pedoclimatic production constraints, the latter mainly determined by their location in Africa. The eco-efficiency also depends on the level of mastery of the technology by the producer which will allow him to reduce the negative impacts of cultivation under cover compared to cultivation in the open field. The combination of an optimal mastery of the technique of the use of nets – through training imparted to the producers – with the choice of regions of production best suited to this technology should make it possible to reduce the environmental impacts of market garden production in sub-Saharan Africa. A synergy of action between experts and researchers in the disciplines of agronomy, economics, socio-technical analysis and the environmental assessment of systems will be necessary to achieve an optimal coherence and the best representation possible of these joint approaches. An example of this synergy can currently be found in two ongoing projects on the continent: ANR-Eco-Plus in Kenya (2017-2020) and HortiNet in Côte-d'Ivoire (2018-2021).

Conclusion

Our first observations in Benin and Kenya suggest that the physical control of insects through the use of nets leads to profound changes.

It promotes a reduction in pesticide use. Tested on the farm, the nets decrease, as expected, the prevalence of worms and caterpillars that directly attack fruits and leaves. And since, in the majority of cases, producers apply pesticides based on an observation of the prevalence of pests and the damage caused by them (damaged fruits or perforated leaves), the protection provided by the nets leads them to reduce the frequency of phytosanitary treatments significantly.

It also allows farmers to assess the benefits of using nets. After all, weren't nets first used in Europe on the initiative of the farmers themselves? By cultivating under nets, the farmers discover that it is possible to produce more with a reduced use of phytosanitary products and to overcome the challenge and the problems posed by the building up of resistance to insecticides. In Kenya, the dissemination of the innovation is facilitated by a cool high-plateau climate and thus by the greenhouse effect of the nets, which is beneficial to yields. In Benin, the dissemination will probably be slower because of the humid climate, which limits yields, and the lack of distribution networks for nets.

The dissemination and adoption of nets also facilitates the networking of actors. In Kenya, net-distribution projects have thus contributed to bringing together stakeholders with an interest in organic agriculture (WhatsApp group). On the one hand, a number of pioneers have emerged, and have become role models for groups of farmers who want to get involved. On the other, links have been created between these groups of farmers and innovative companies specializing in the supply of biological protection tools.

Finally, this initiative has allowed the formulation of targeted policies for a transition to agroecological farming. Very often, the transition to organic farming or agroecology is perceived by farmers to be a risky gamble. However, the confined cultivation environment provided by nets makes non-chemical methods of crop protection more efficient and less uncertain. The nets thus become a lever of transition towards these sustainable cultivation methods. Support policies targeted by producer type thus make eminent sense.

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